CL 95-0093

RESULTS OF JPL PROCESSING OF LeRC "ROUND ROBIN" TIME HISTORIES

J. H. Wise, J. A. Zavala, C. L. Sydnor
Jet Propulsion Laboratory, California Institute of Technology

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1 INTRODUCTION.

Four 100 second time histories were provided to interested participants in the Principal Investigator Microgravity Services (PIMS) office of Lewis Research Center (LeRC) for their "Round Robin" comparison of processed flight micro-gravity (μg) time history data. The Jet Propulsion Laboratory (JPL) is pleased to participate in this effort to understand differences and standardize processing techniques within the industry, Requested information for plots of each time history is repeated below for the reader's information:

With "DC" value (if any) removed (i.e. de-meaned), a hard copy of:

1, Plots of acceleration vs. time.

2. Power Spectral Density plots with units of g^2/Hz. The plots should be annotated with:
   a) The composite root-mean-square (grins) for each PSD.
   b) The resolution bandwidth (delta f) used in converting between time and frequency domain.
   c) Number of spectral averages contained in the PSD.
   d) Description of any other processing parameters implemented (e.g. time domain windowing, weighting algorithm, frequency smoothing algorithm, redundant averageing, etc.)
   e) The name and brief description of the software package used if it is obtained commercially or from a third party. The DFT or FFT algorithm used by the package, if known.

3. Plots of running RMS vs. time, maximum value vs. time, and minimum value vs. time (you choose the window length).

4. RMS or variance for each total record.

5. Measured "de" value for the full record length, if any.

6. The equation used by your software for calculating mean values.

7. Any other information related to your processed data which you feel would be of use in characterizing your results.

1.1 Data Types and Comments.

Four 100 second flight data files were provided for analysis for the participants. File names are QUIET.ASC, EXERCISE.ASC, THRUST.ASC AND ROTATION.ASC. It is assumed that the file names are indicative of the type data to be processed.

Power Spectral Density (PSD) plots were requested for all 100 seconds for all files. A visual inspection of all files did not show evidence of saturation, however, the only file showing evidence of stationarity was the file named QUIET.ASC. All others exhibit various forms of non-stationarity. In assessing these data, users must recognize their limited usefulness. Section 3 presents some suggestions for presenting data in a more useful manner. In addition, some data were processed in a manner not requested by LeRC, but which could provide additional information and understanding for the ultimate user.

1.2 Processing Information and Parameters. The data in this report are processed with Synergistic Technology Inc. VAMP software, which produced the PSDs utilizing the algorithm:

PSD(j) = ((DATA_real(j)**2 + DATA_imag(j)**2)/DIV)/2

where DIV = (last spectral line frequency - 1st spectral line frequency)/(number of spectral lines-l). The Running Time Histories were produced with DSP Development Corp., DADiSP software.

2 PROCESSING RESULTS

2.1 QUIET.ASC File Data. The complete time history is shown in Figure 1A through D. Visual inspection samples of the time history shows no evidence of saturation and appears to be stationary. Figure 2 shows running root mean square (RMS), maximum value, and minimum value vs. time in one hundred, 1 sec. contiguous increments. We were unsure about the meaning of item 3, "minimum value" in enclosure 1 to the LeRC cover letter and Melissa Rogers stated that it meant to plot maximum negative m addition to maximum positive and RMS. This results in our plot of the envelope of time history with the RMS level between the two. This plot is referred to as "running time parameters" for each of the four files.

A probability density plot (Figure 3) looks reasonable for a quiet period, showing some deviation from a Gaussian distribution, but this is understandable in view of the systems on board the shuttle necessary to support vital functions. The principal contributor to the deviation is probably due to the narrow resonance m the PSD plots, at approximately 17 Hz and resembling kurtosis (described in Section 3. 1). The curve is not well defined in the plot, but the shape of a pure sinusoidal probability density plot displays two peaks either side of zero sigma, corresponding to the negative and positive peaks of a sine wave, and a minimum value at zero sigma corresponding to the data zero crossing. The plot in Figure 3 would be typical of a sinusoid superimposed on random data where the sinusoid is not very high compared to the random noise. A Gaussian distribution is a strong indicator of stationarity and a constant amplitude sine wave is stationary by definition, therefore the combination is considered to be stationary also.

Narrow falter band PSD analyses were processed for 3 and 12 averages (n=6 and n=24) to show fine frequency resolution which is not available for 100 seconds of data at acceptable confidence levels, and 48 averages (n=96) which is acceptable for stationary data confidence (see Figures 4 A,

B & C). To obtain the same frequency resolution at higher confidence levels, the data sample length must be much longer. Both Harming and Kaiser-Bessel weighting functions are used to show how different weighting functions a.fleet these and all other plots for time history files supplied by LeRC (see Section 3,3 for a comparison of weighting functions). QUIET.ASC data files show that Harming and Kaiser-Bessel weighting functions show no significant PSD differences, but other LeRC data files show more significant amplitude differences due to spectral differences, that the effect of different weighting functions and filter bandwidths have on different spectral data and non-stationary data.

2.2 EXERCISE.ASC File Data. An examination of the EXERCISE.ASC time history data file (Figure 5) shows three large transients at 30, 40 and 50 seconds plus some smaller ones, and an amplitude increase from 62 seconds to the end of the file. Figure 6 is the Running Time Parameters for the EXERCISE. .4SC file These all contribute to the kurtosis shown in Figure 7 which is a Probability Density plot of the 100 second data during an exercise period. Figure 6 is the running time parameters for the EXERCISE. ASC file. The probability density and time history plots indicate non-stationarity.

An examination of PSD data processed with Harming and Kaiser-Bessel weighting functions (see Figures 8A, B and C) display differences which can be attributed to the weighting function discussion m Section 3.3. There is approximately a 10 dB, narrow dip in the plot for the Kaiser-Bessel weighting function compared which Harming data cannot distinguish. However, Harming displays narrower peaks than Kaiser-Bessel for each of the different frequency resolutions. Other files show discrepancies in data plots due to falter bandwidth and weighting function differences and data must b eexamined to determine if the differences are due to filter bandwidth differences or filter side lobe leakage differences. When comparing data from different sources, these factors must be considered.

The more averages processed, the greater the smoothing as shown in Figures 8A, B and C. At lower frequencies where the bandwidth is more spread out due to the logarithmic plot, the resonance at just over 1 Hz in Figure 8A is narrower for Harming than for Kaiser-Bessel weighting because of the noise bandwidth differences, but the approximately 10 dB dip just prior to the peak does not show because of signal leakage into the Harming side lobes, Figure 8B filter bandwidth is approximately four times wider than Figure 8A and the dip just after 1 Hz is no longer visible because of the wider bandwidth. Figure 8C shows the same data plotted for 48 averages and 0.49 Hz filter bandwidth. These clearly show the necessity for narrow band analysis, where data file lengths are sufficient. A larger number of averages produces a smoother plot with less amplitude variation and wider bandwidth has a similar effect by masking fine data peaks and valleys. Note the narrow band peaks m all plots at 17 Hz. AS the filter bandwidth is increased, the amplitudes decreases. This inverse relationship between bandwidth and amplitude is discussed in section 3.2.

2.3 THRUST.ASC File Data. This data file is very non-stationary and PSD plots are not advised for any non-stationary data, but PSDS are provided in accordance with instructions. Time history data shows a majority of data around zero with nine transients of varying length, shape and amplitude (see Figure 9). Transients should be processed as energy spectral densities and averaged similar to PSDs,

but they must be statistically equivalent to be valid. Individual energy spectra could be performed, but statistical confidence is very poor because of lack of averaged data. However, this might prove to be "the only game in town". Figure 10 shows the running time parameters for THRUST.ASC file data.

JPL does not have software to produce the energy spectrum at this time, but has the capability of writing it if funding were available, and therefore this data is not reported. Transient PSD data will be severely distorted by the large percentage of data around zero as the data is averaged over the total time history. The probability density plot of Figure 11 shows a very large kurtosis as a result. .4n additional error is due to the contribution of random noise in the transients.

It is interesting to note the large spectral differences for Figures 12A, B and C which can be attributed to the very poor statistical confidence we have, that three and twelve averaged PSDS is representative of long time averages of random data. In particular, note the average amplitude levels below 1 Hz and the difference in the broad spectral peaks between 1 and 5 Hz in Figures 12A and B. The differences are probably due to non-stationary data in the peaks at approximately 5 and 10 Hz in Figure 12B and may possibly also be attributed, in part. to the effects of different weighting functions.

2.4 **ROTATION.ASC** File Data. There are small disturbances in the time history of Figure 13 at approximately 25 and 48 seconds in addition to a Larger transient about 40 seconds, while Figure 14 shows running time parameters for the ROTATION.ASC data file. Figure 15 shows a probability density plot that is typical of a narrow band resonance with a positive bias, superimposed on random data. An examination of Figures 16A, B and C show a large narrow resonant peak at approximately 17 Hz which is probably the cause of the kurtosis in Figure 15. Differences in amplitude levels in Figures 12.4 and B are an indication of the problems which can be encountered when there are an insufficient number of averages to provide sufficient data confidence. Only an attempt to identify narrow band data resonances justify such poor data confidence.

3 COMMENTS AND SUGGESTIONS.

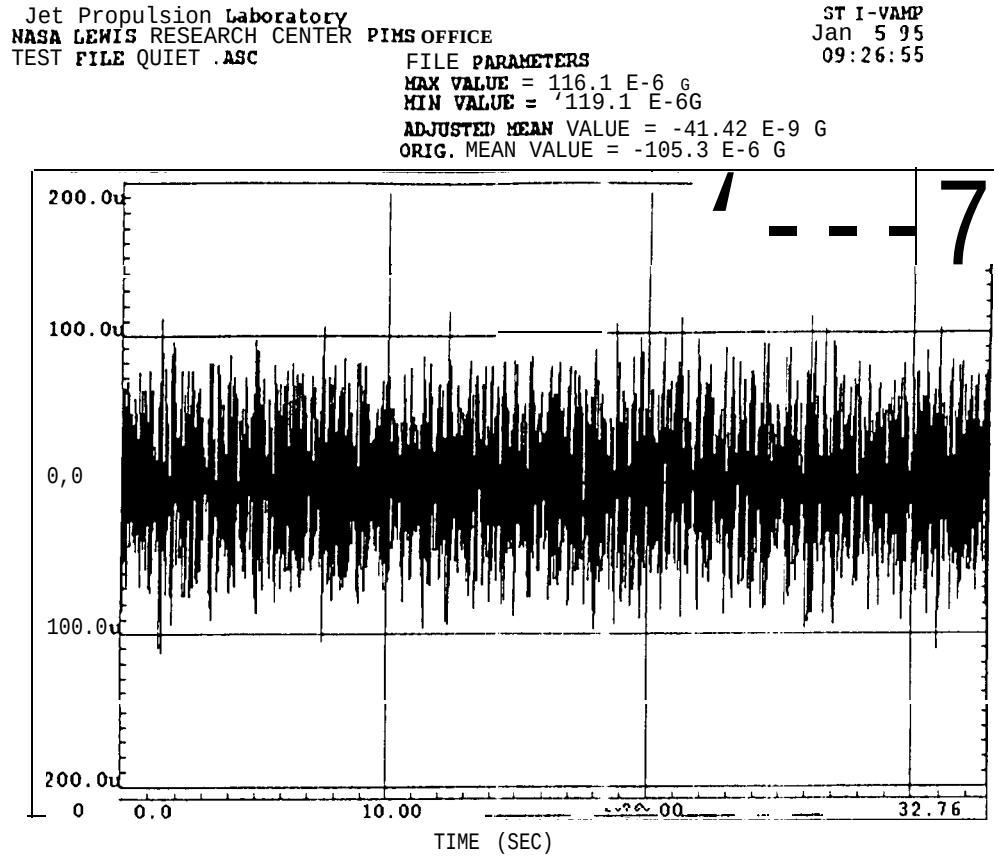
3.1 Moments. Probability density plots provide clues to data validity and problems associated with PSI%. Certain deviations from a standard deviation (Gaussian distribution) are referred to as moments which describe statistical properties of data. The first and second moments are the mean and the variance about the mean, which are understood by most experimenters. The third and fourth are not as widely used and so are less understood. The third moment is called skewness and describes asymmetry of data. It is characterized by a deviation from the Gaussian curve by "leaning" of the probability density plot to the right or the left. The fourth moment is called kurtosis and is characterized by either a high narrow peak, or a broad low peak compared to a Gaussian distribution. Examples of kurtosis are shown in probability plots for the LeRC data files. More detailed moment information can be found in text books on statistics.

3.2 Filter Bandwidth Comparison. Another factor that may cause discrepancies is processing with different filter bandwidths at different labs. The algorithm processing the data assumes white noise within each falter bin. Consider a hypothetical case where one source uses a 10 Hz filter bandwidth and the second uses 1 Hz. If the data contains a relatively high, very narrow band resonance, PSD resonant data processed by the first will be divided by ten and the second will be divided by 1 which could lead to a 10 dB difference in the plot of the same very narrow resonance. For this reason, the data should be analyzed with a filter bandwidth at least one fourth of the data resonance bandwidth if the file length is sufficiently long to assure sufficient data confidence. Otherwise. a narrow band, lower confidence analysis should be performed to determine the data bandwidth and then calculate a correction factor for data processing bandwidth error, In order to control these types of data differences, processing parameters should be specified for all labs to follow.

3.3 Weighting Function Comparison. It is pertinent to review some aspects of weighting functions to better understand data differences for data files processed with Harming and Kaiser-Bessel weighting functions. Figure 17 is a comparison of several weighting functions, including Harming and Kaiser-Bessel. Using the rectangular (or boxcar) weighting function as a reference, the Harming weighting function noise bandwidth is 1.5 times the rectangular weighting function, while the Kaiser-Bessel is 1.8 times it. The first Harming function side lobe is 38 dB below the peak, while the Kaiser-Bessel is 70 dB below the peak. Side lobe rolloff for the Harming weighting is 18 dB/octave and the Kaiser-Bessel is 38,5 dB/octave. Both of these characteristics of the Kaiser-Bessel weighting function can provide better resolution than the Harming function where signals are leaked into filter side lobes. In spite of the fact that the Harming weighting function has an advantage over the Kaiser-Bessel, in that it has a narrower noise bandwidth, more adjacent signals can be included in any particular Hanning frequency bin than can be seen in the Kaiser-Bessel bin. This is dramatically illustrated in Figure 7A, just above 1 Hz. There is approximately a 10 dB, narrow dip in the plot. An examination of other files can show similar differences in data plots. When comparing data from different sources, these factors must be considered.

4 ACKNOWLEDGEMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.



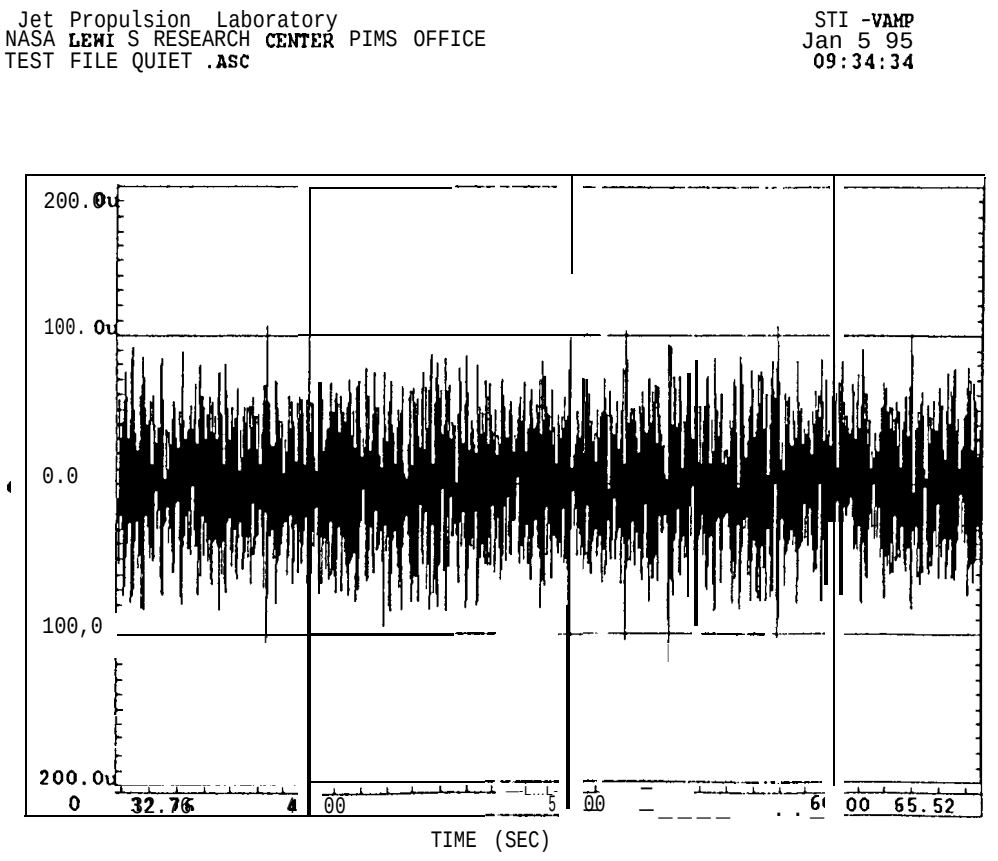
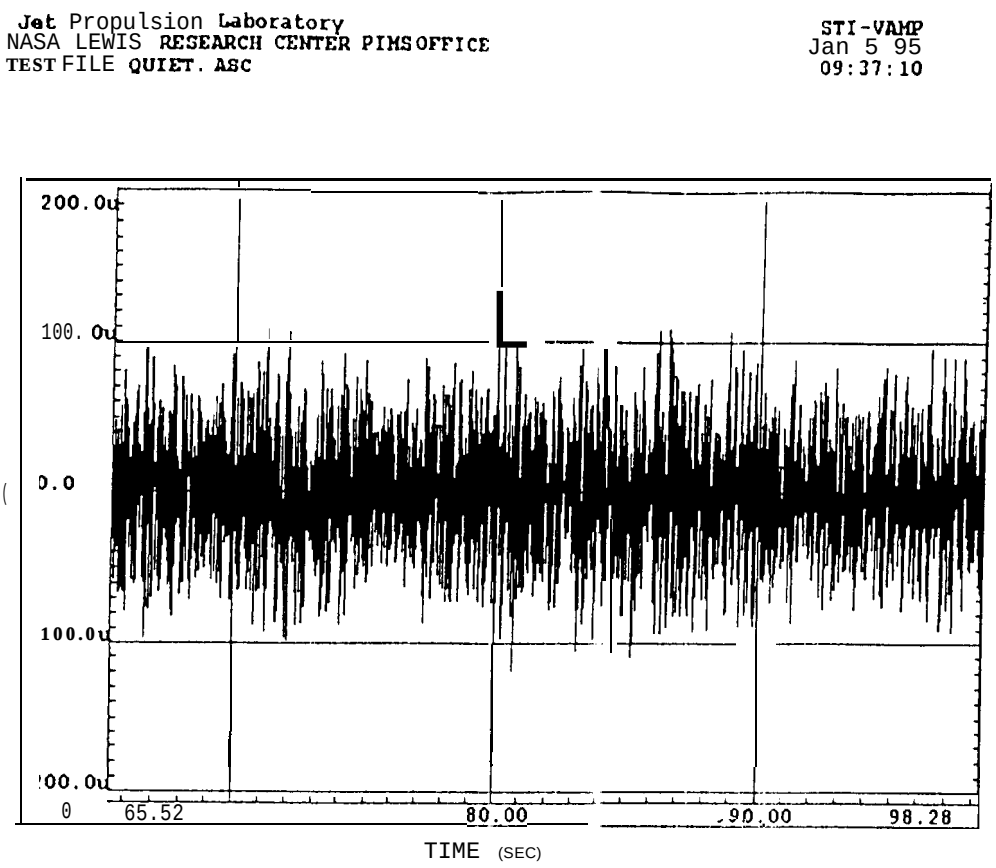


Figure 1. **File QUIET.ASC,** Time History



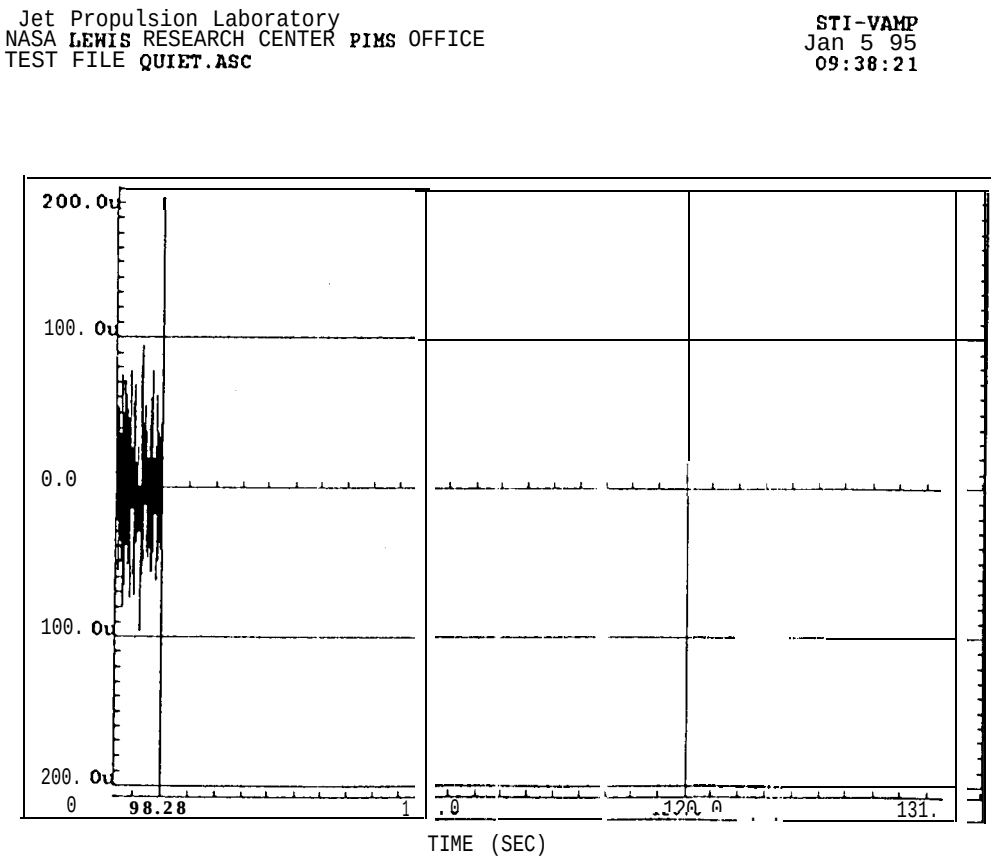


Figure 1. File QUIET.ASC, Time History (cont.)

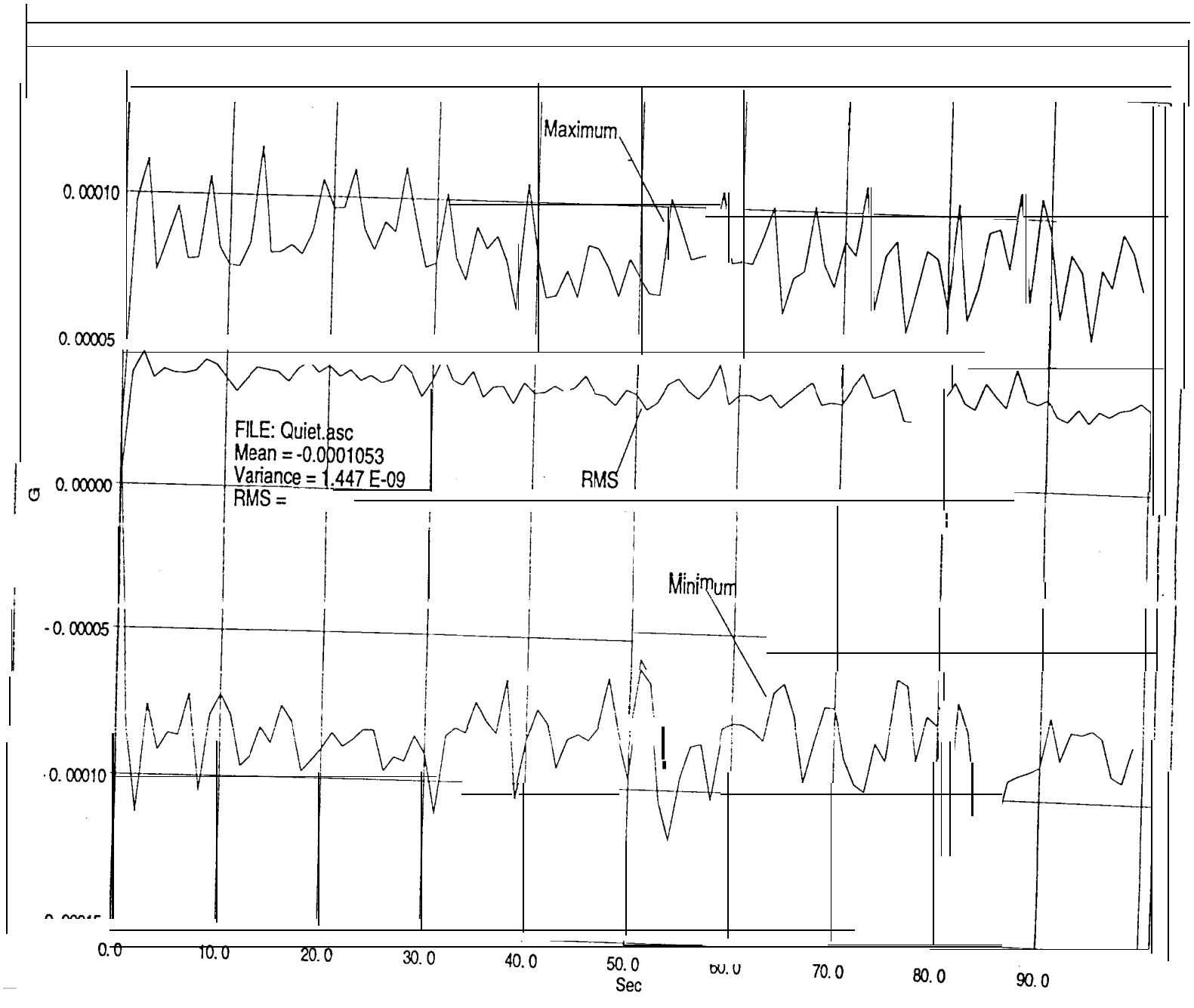


Figure 2. File: QUIET.ASC, Running Time Parameters

Jet Propulsion Laboratory
NASA LEWIS RESEARCH CENTER PIMS OFFICE
TEST FILE QUIET .ASC

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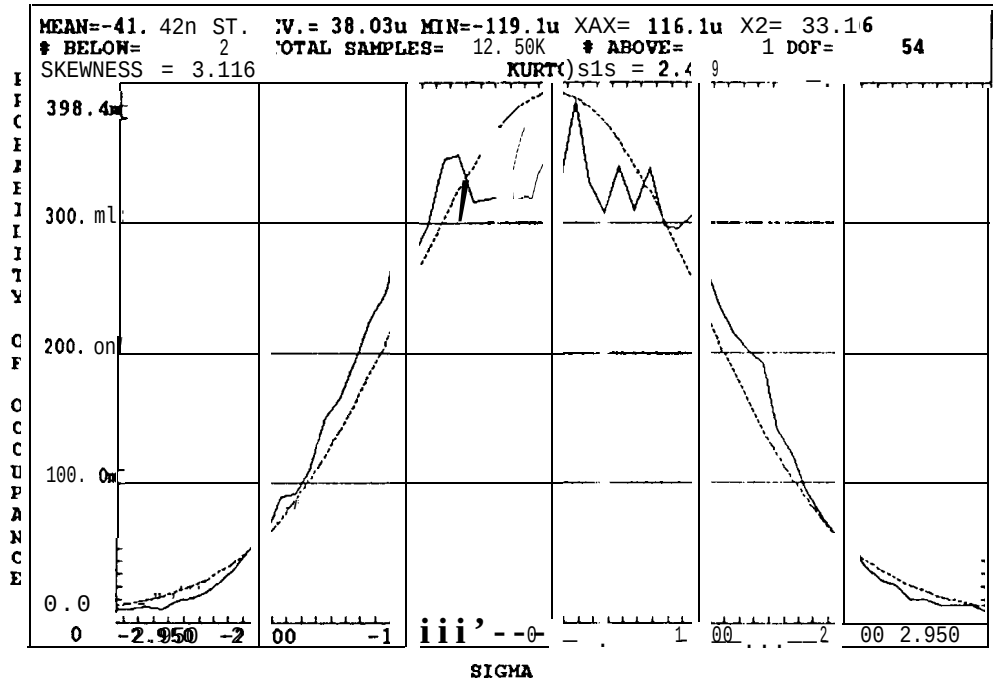


Figure 3. File: QUIET.ASC, Probability Density

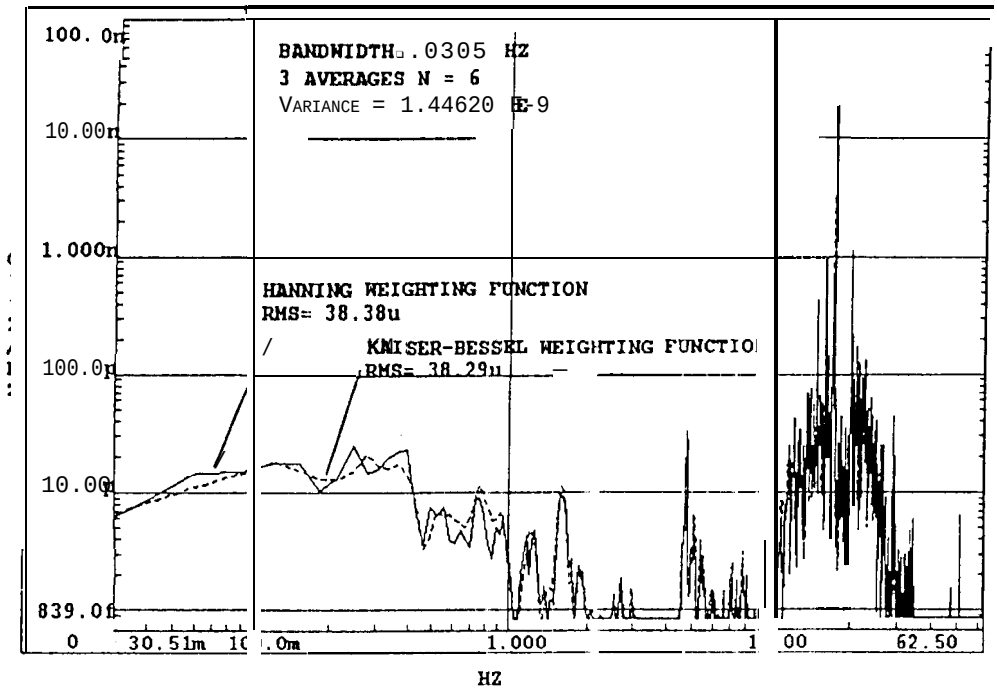


Figure 4A. File: **QUIET.ASC,** PSD, 3 Averages

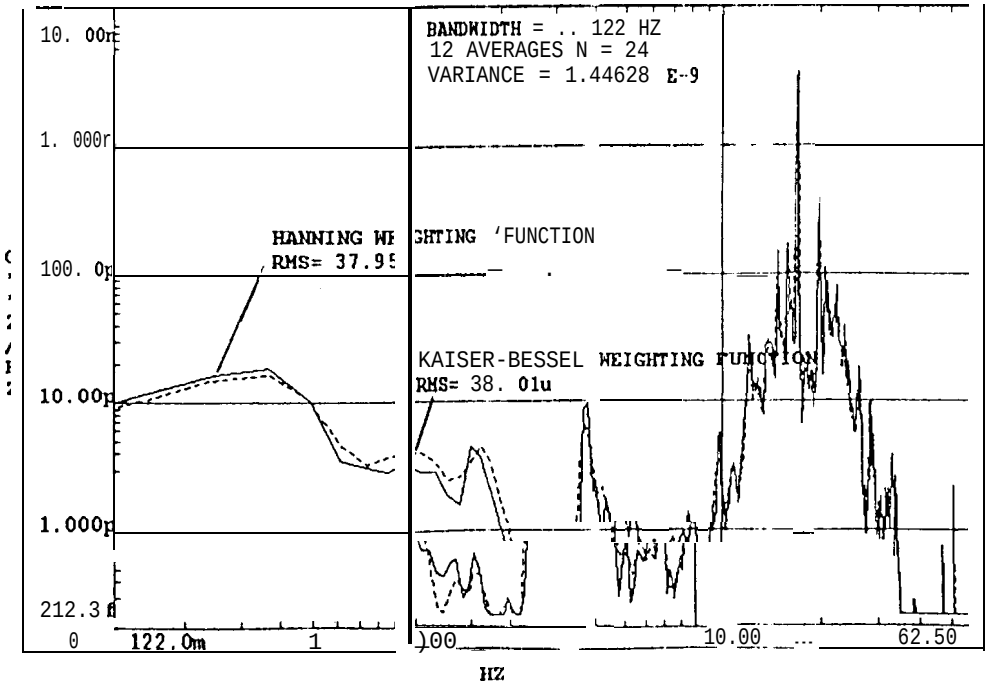


Figure 4B. File: **QUIET.ASC, PSD, 12** Averages

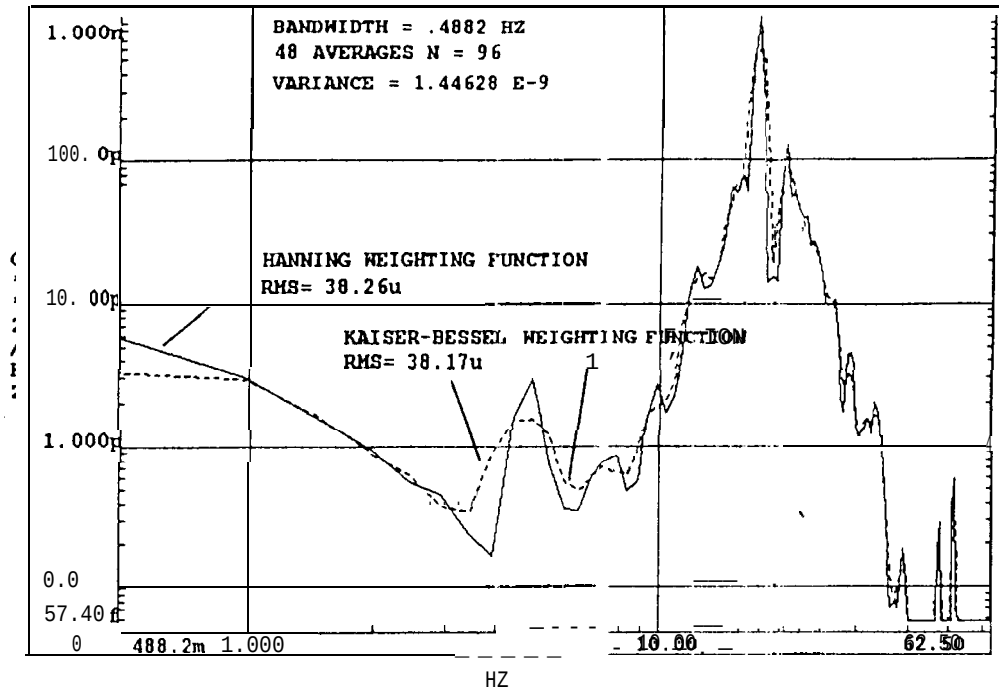
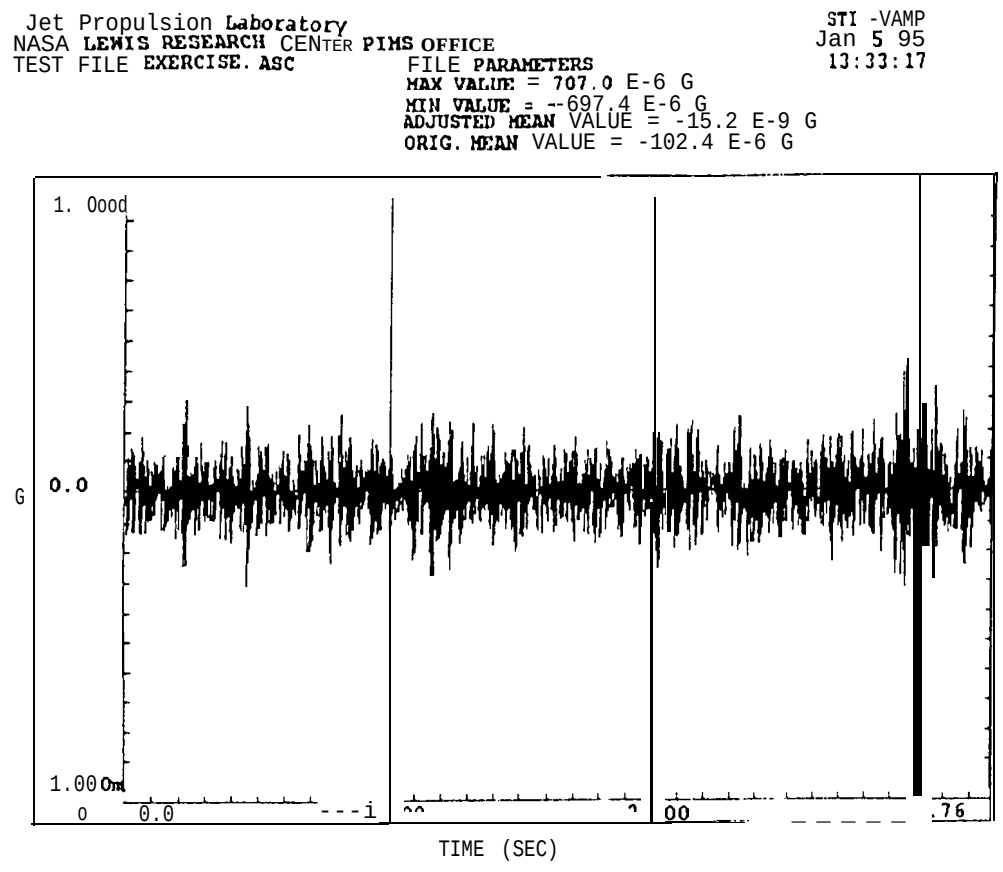


Figure 4C. File: QUIET.ASC, PSD, 48 Averages



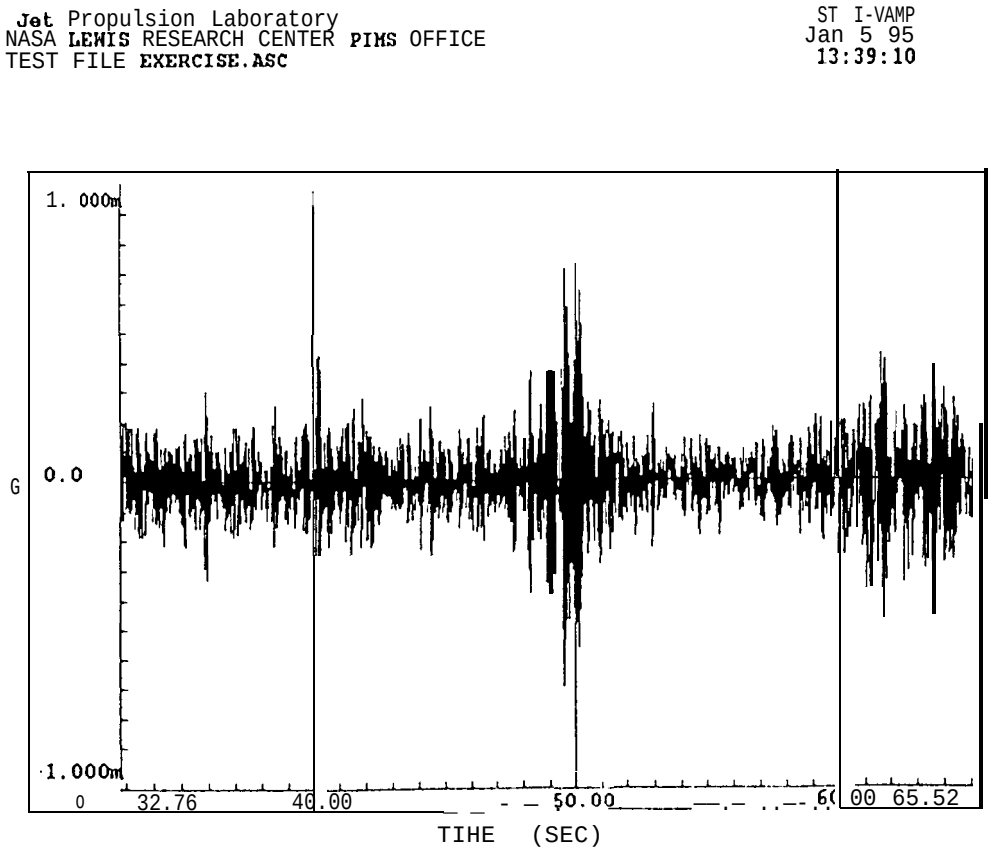
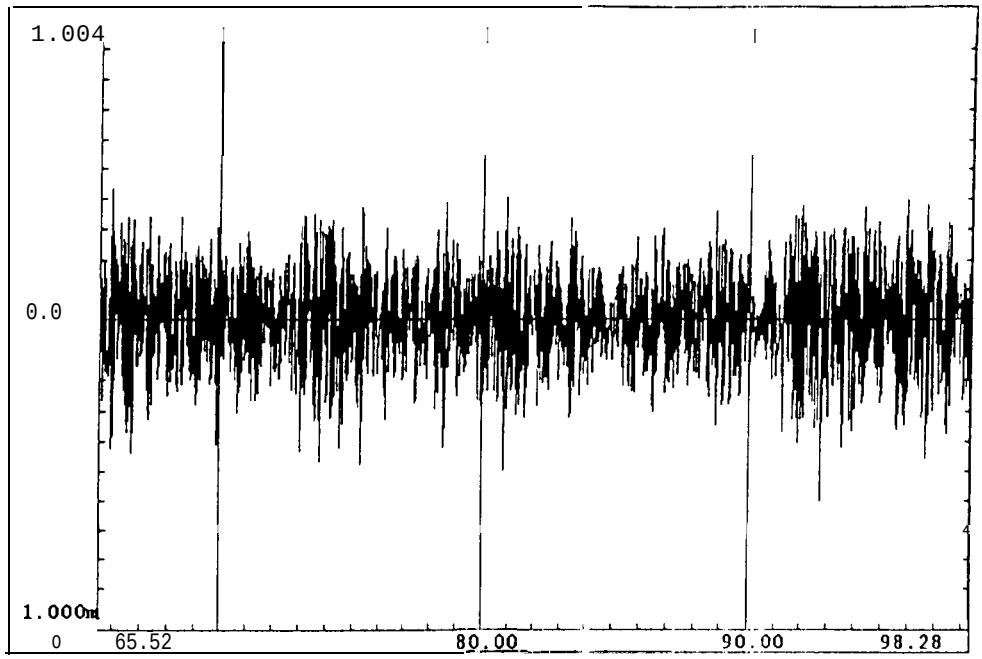


Figure 5. File: **EXERCISE.ASC,** TimeHistory



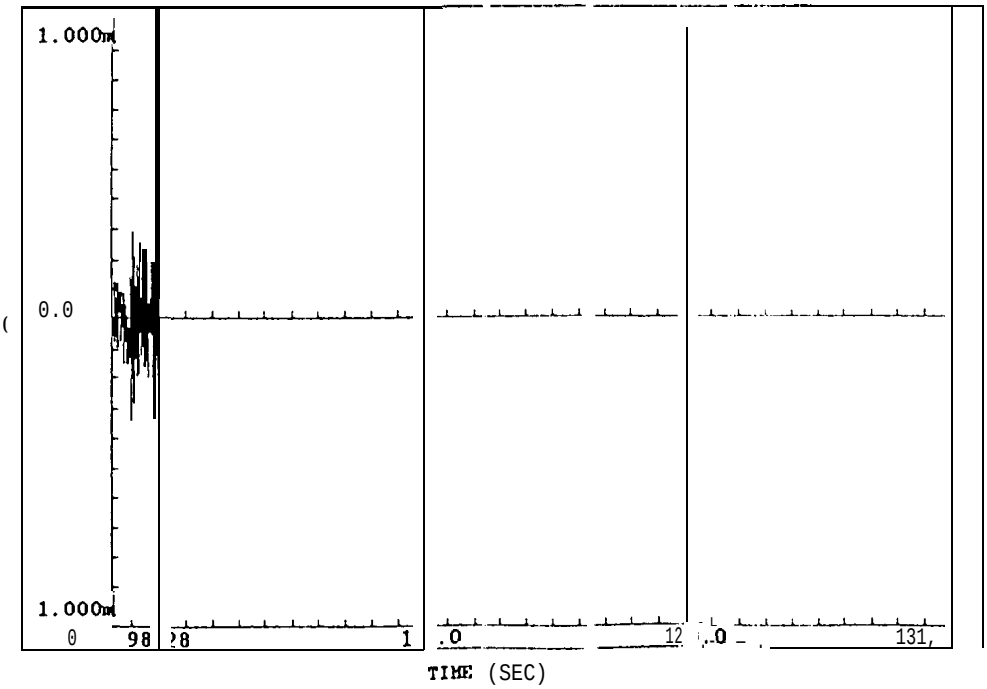


Figure 5. File: **EXERCISE.ASC, Time History (cont.)**

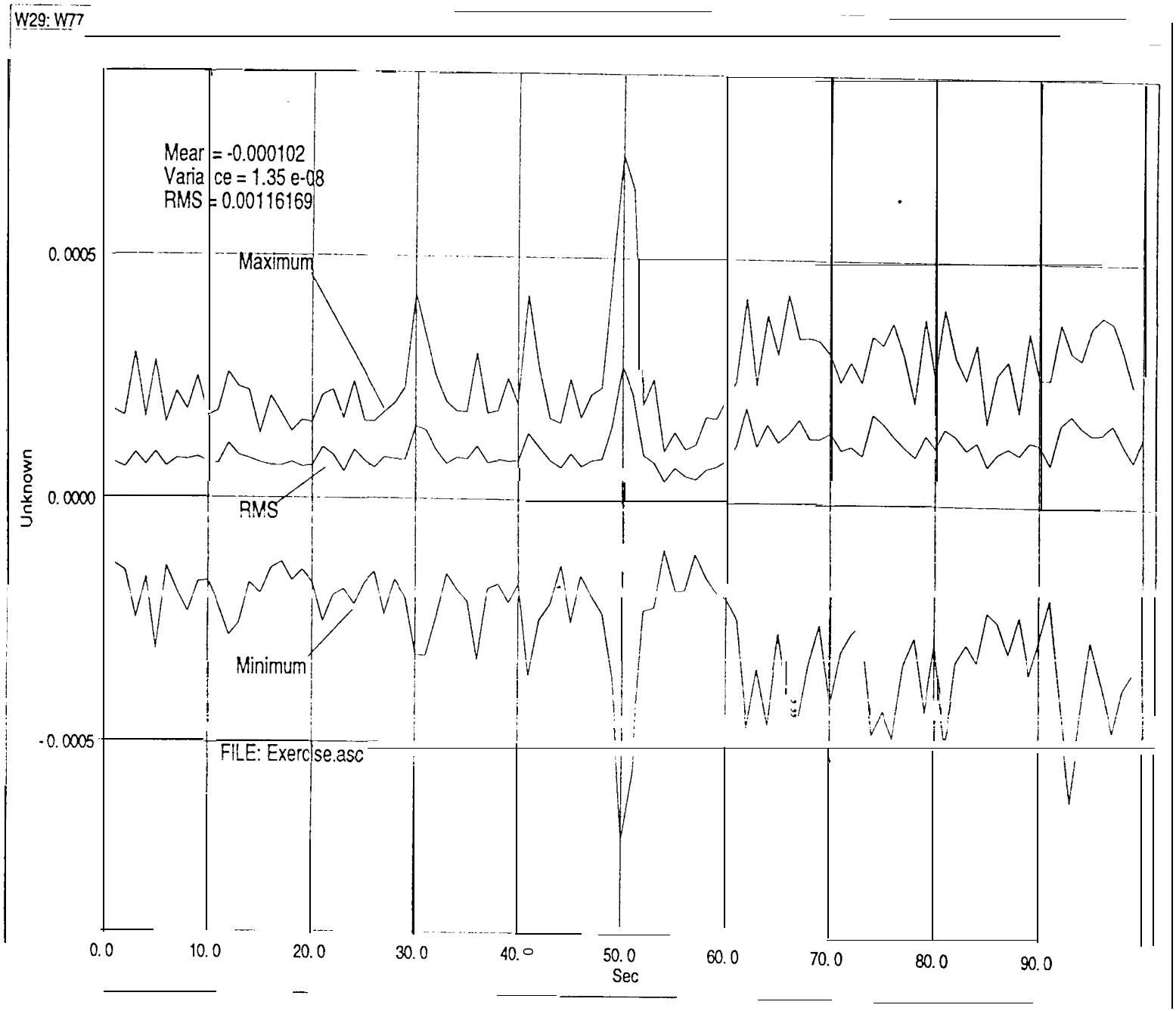


Figure 6. File: EXERCISE.ASC, Running Time Parameters

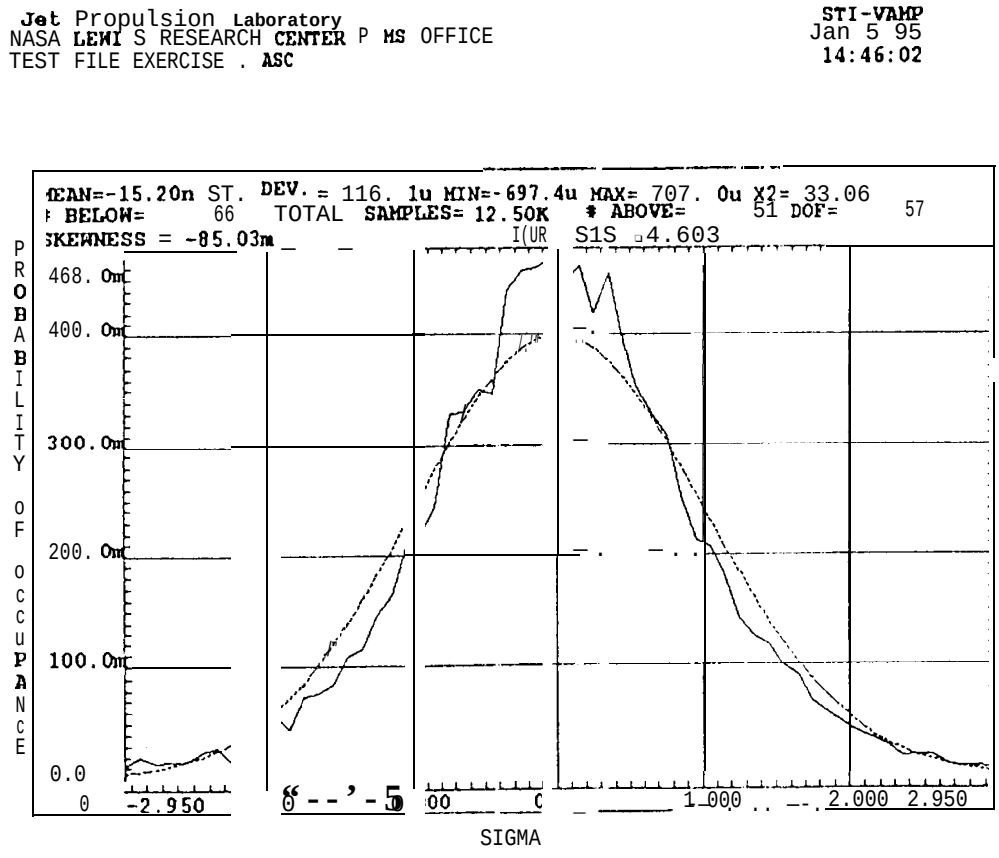


Figure 7. File: **EXERCISE.ASC,** Probability Density

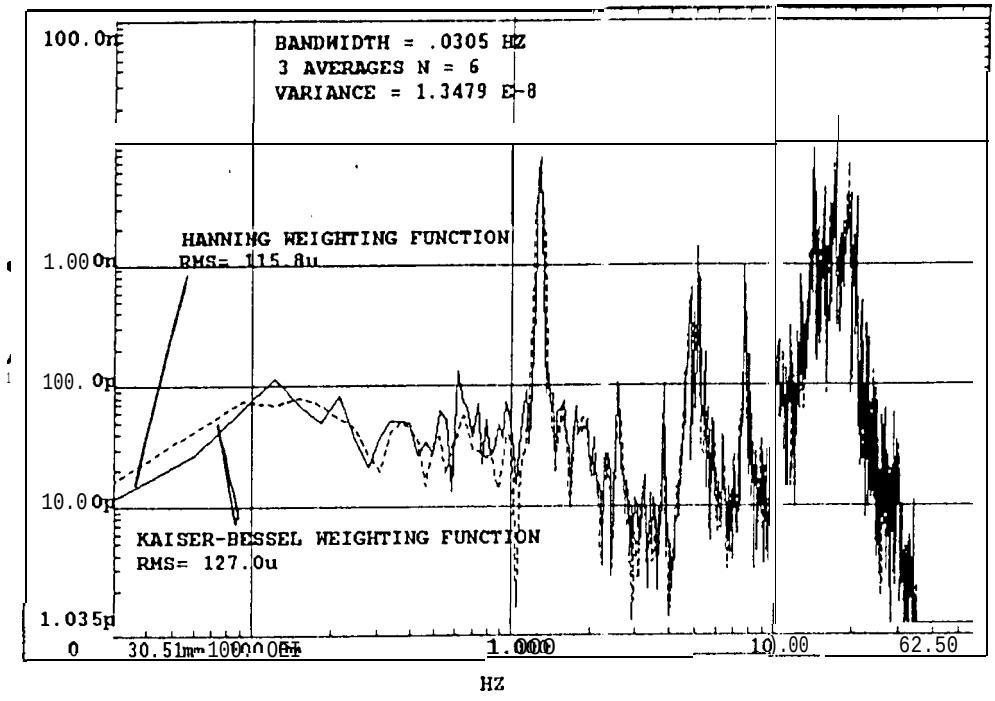


Figure 8A. File: **EXERCISE.ASC, PSD,** 3 Averages

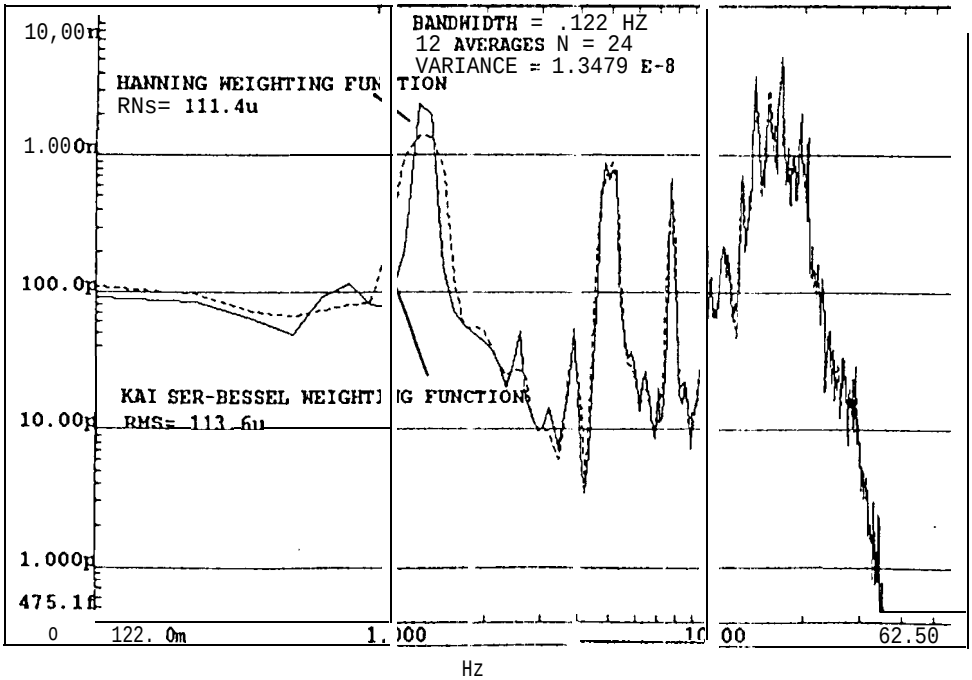


Figure 8B. File: **EXERCISE.ASC,** PSD, 12 Averages

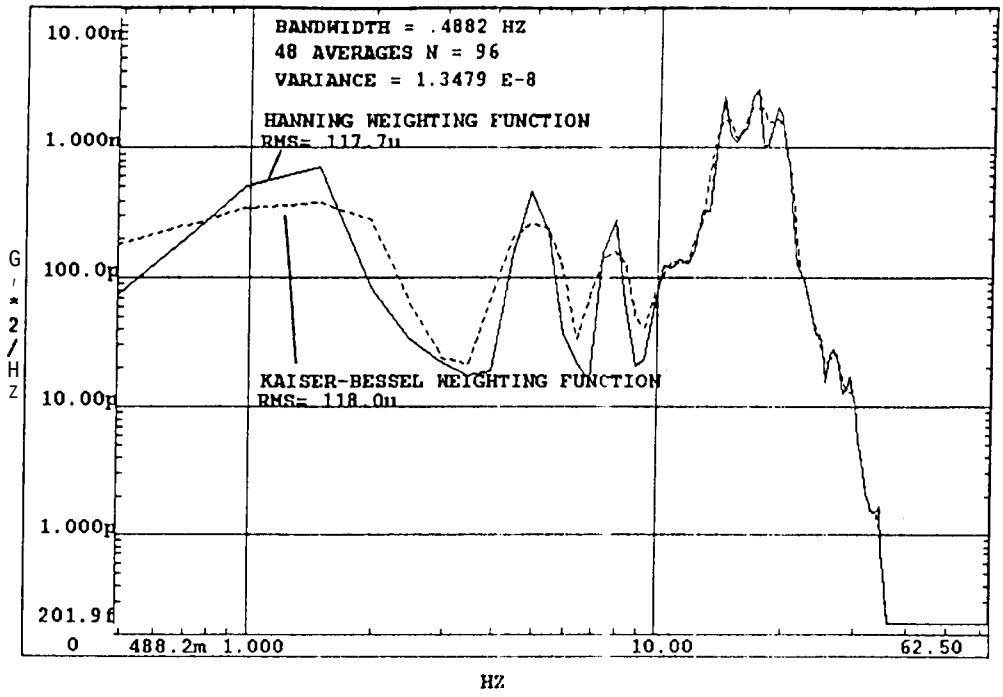
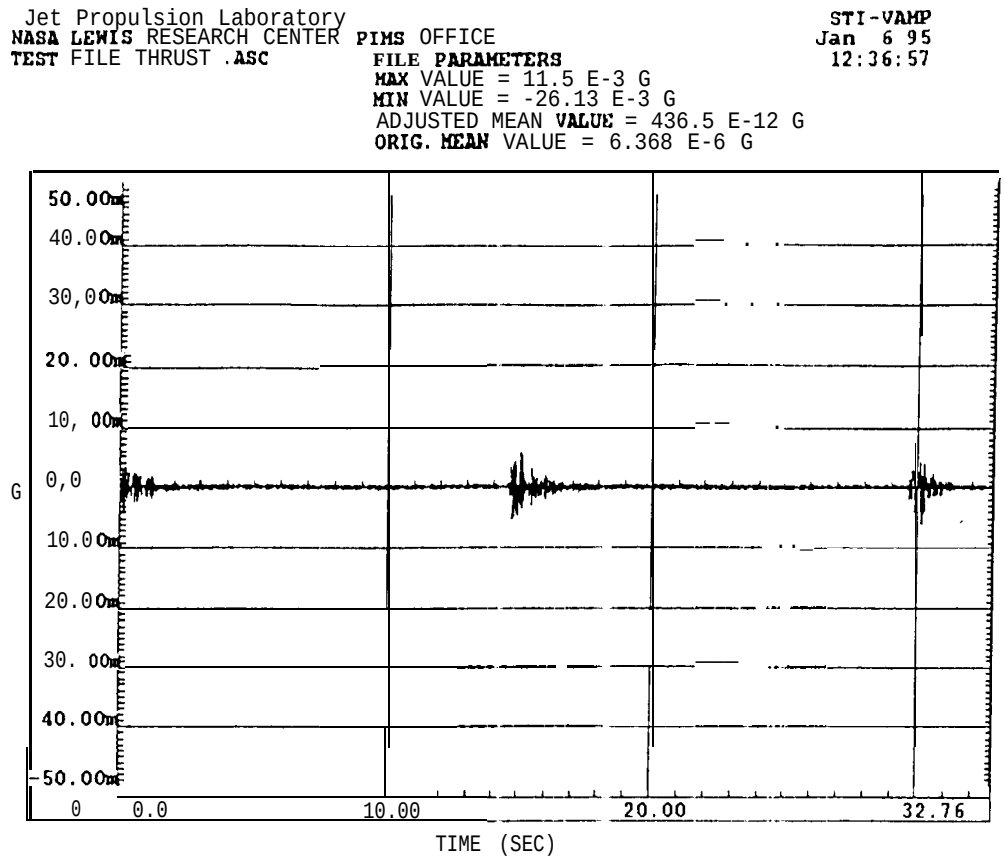


Figure 8C. File: **EXERCISE.ASC, PSD, 48** Averages



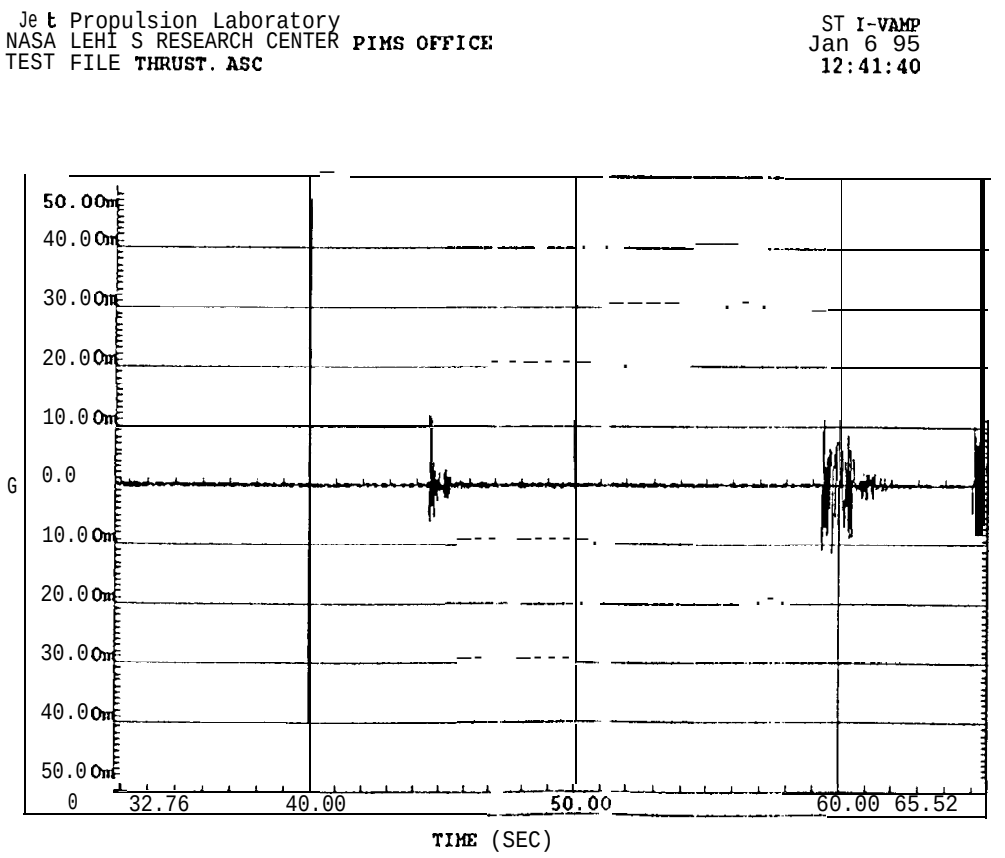


Figure 9. **File: THRUST.ASC,** Time History

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TEST FILE THRUST .ASC

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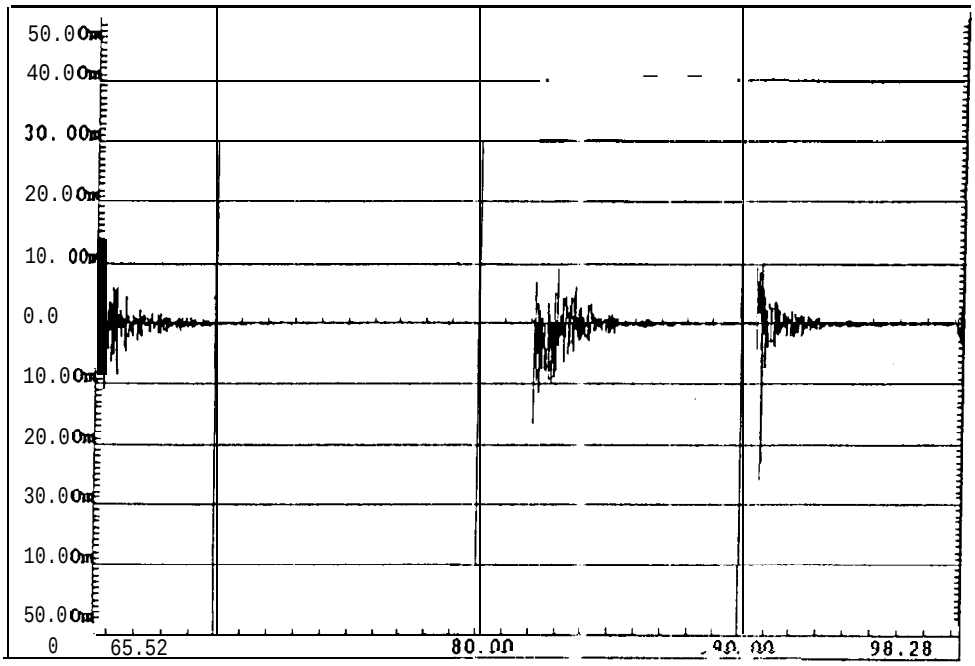

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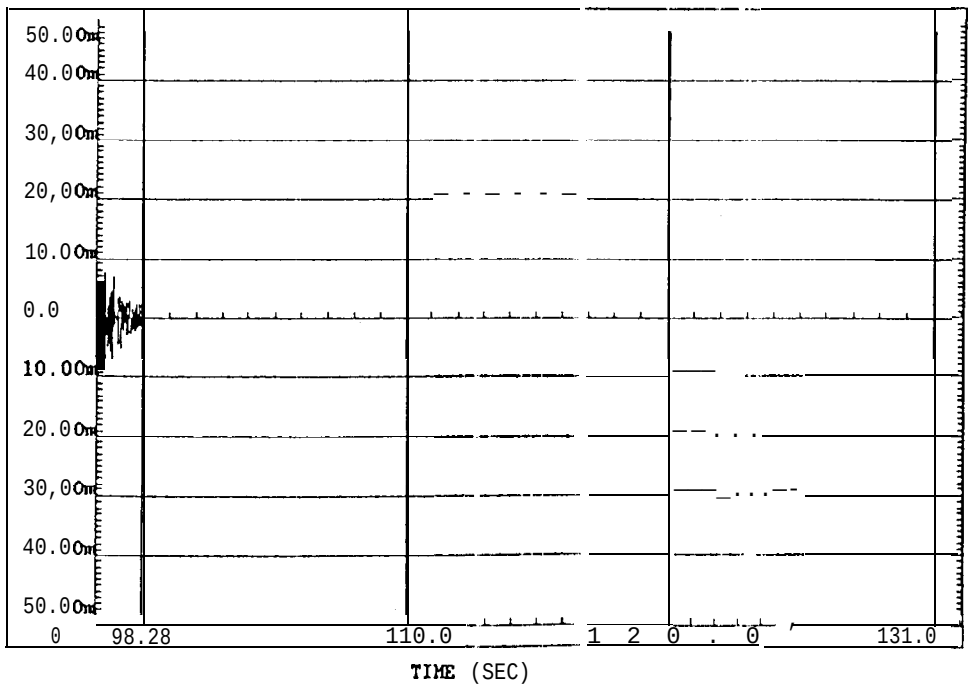

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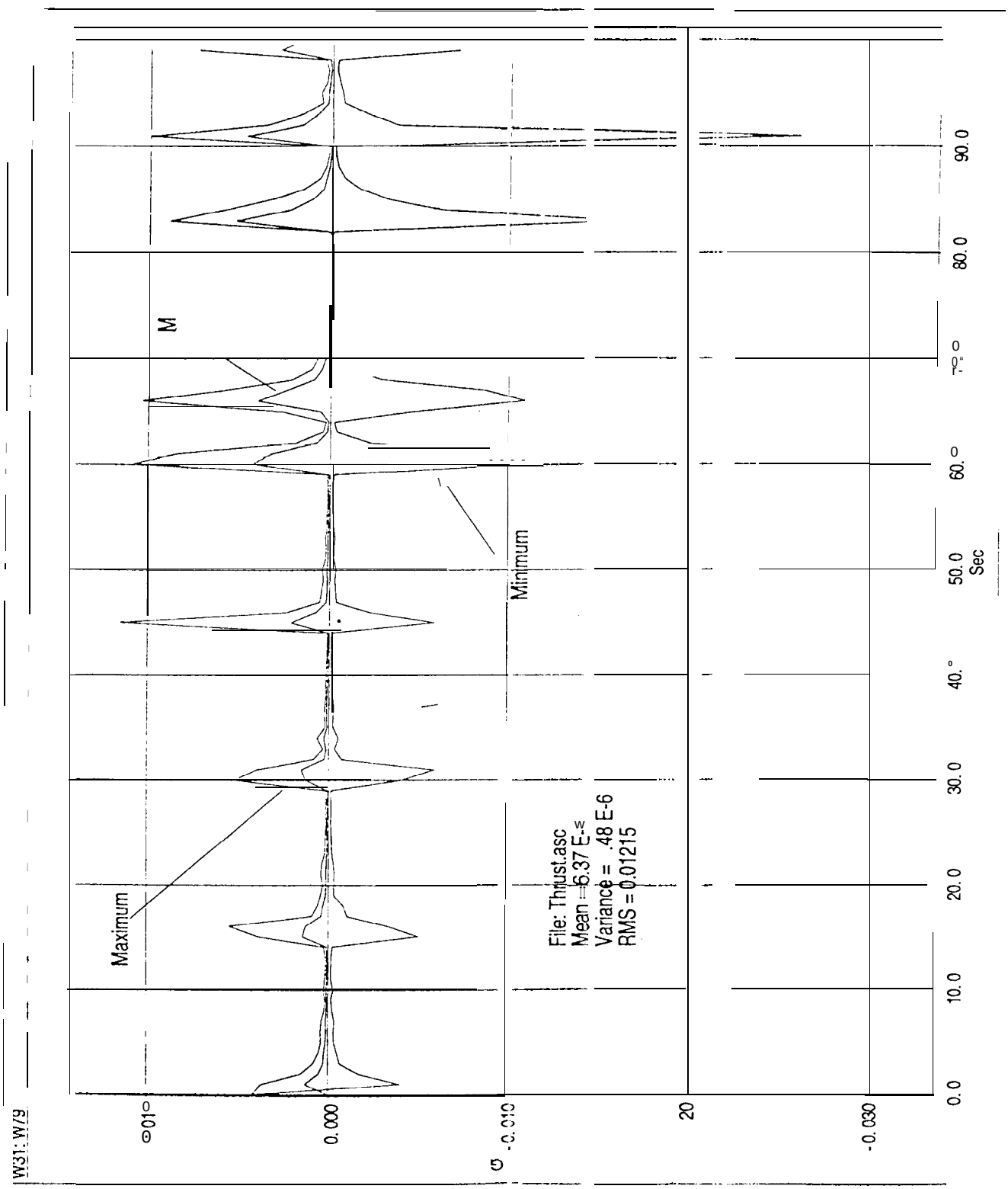


Figure 10. File: THRUST.ASC, Running Time Parameters

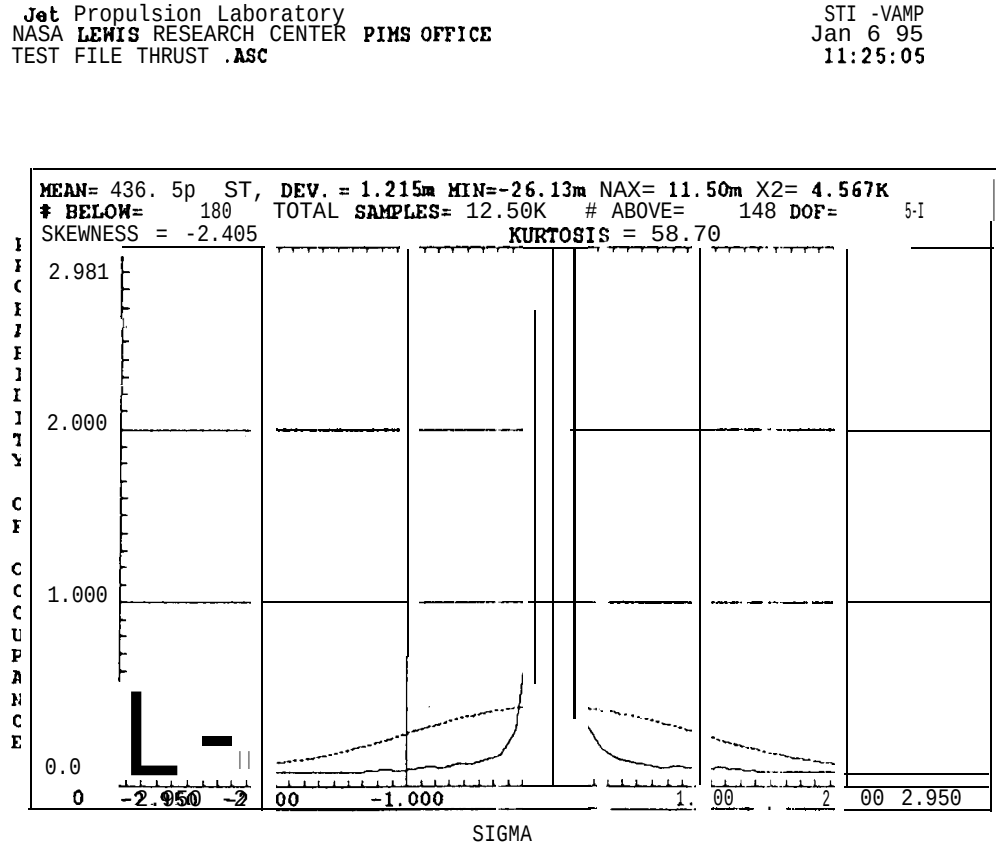


Figure 11. File: **THRUST.ASC,** Probability Density

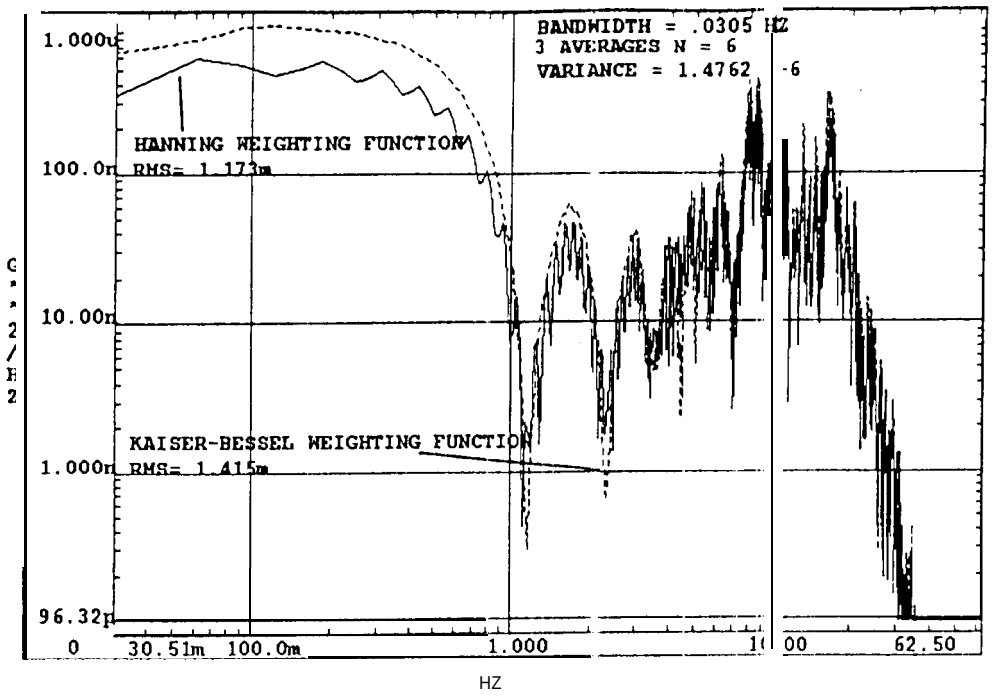


Figure 12A. File: **THRUST.ASC, PSD,** 3 Averages

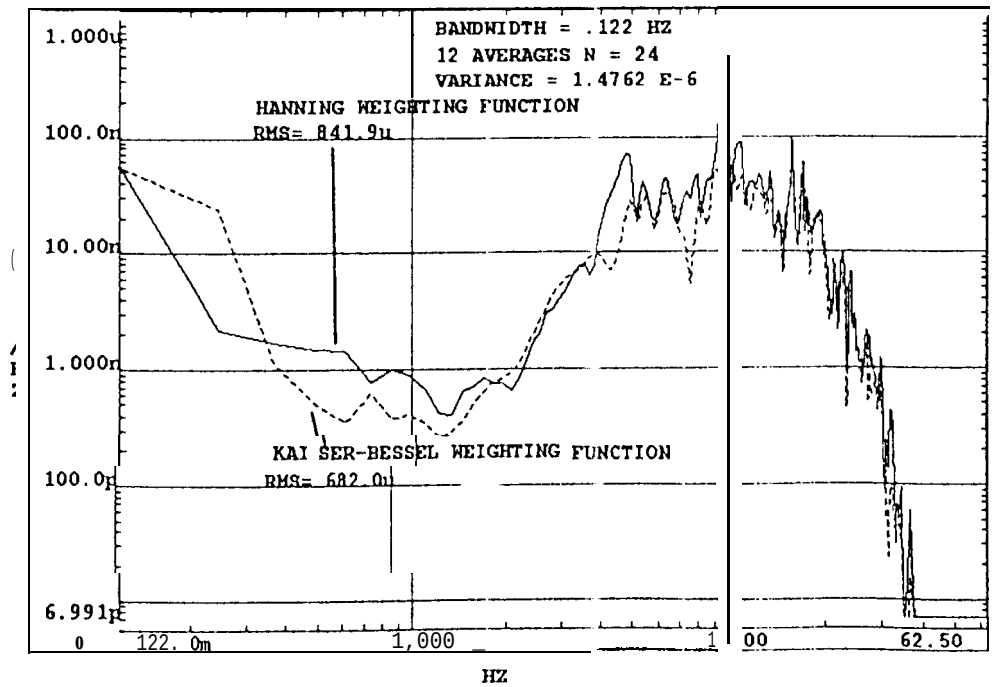


Figure **12B.** File: **THRUST.ASC, PSD,** 12 **Averages**

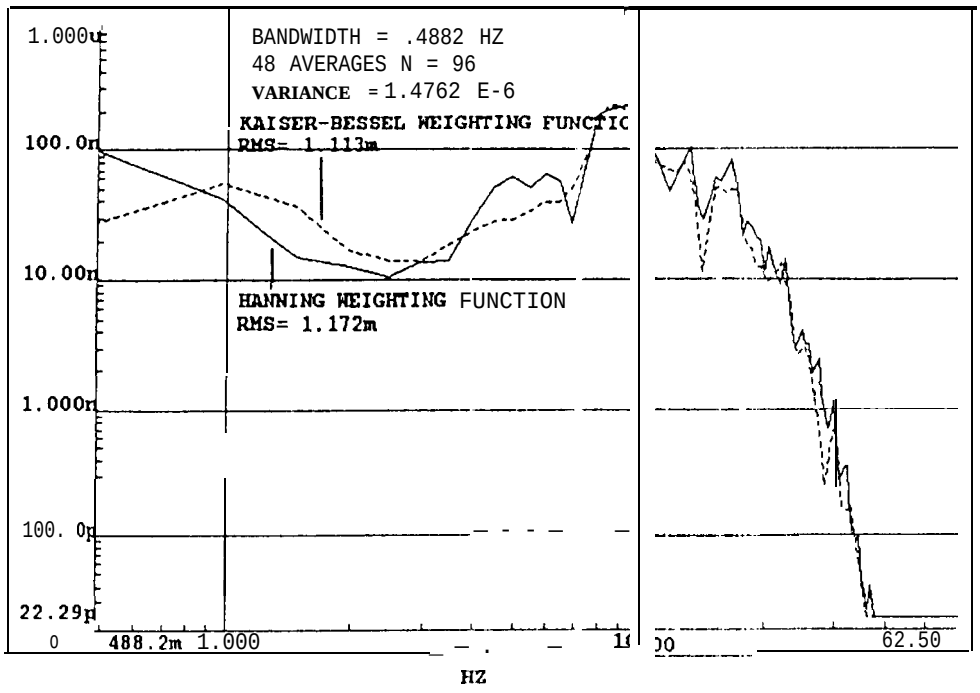
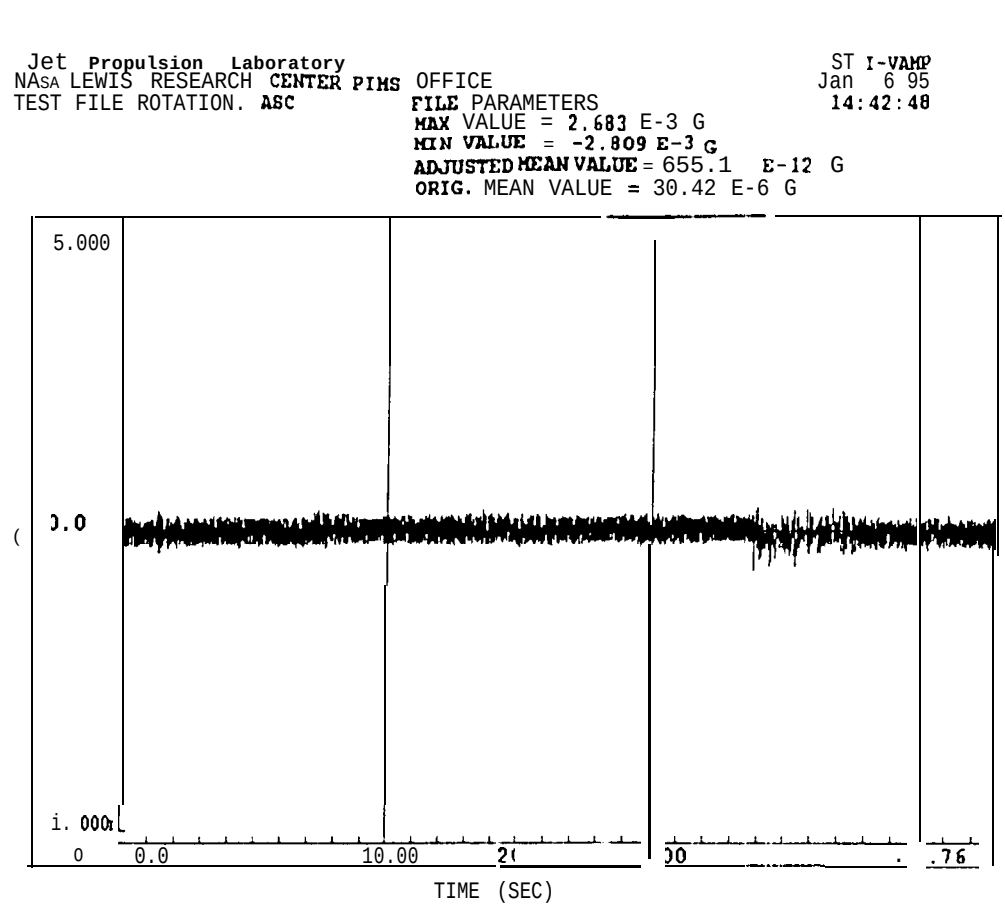


Figure 12C. File: **THRUST.ASC,** PSD, **48** Averages



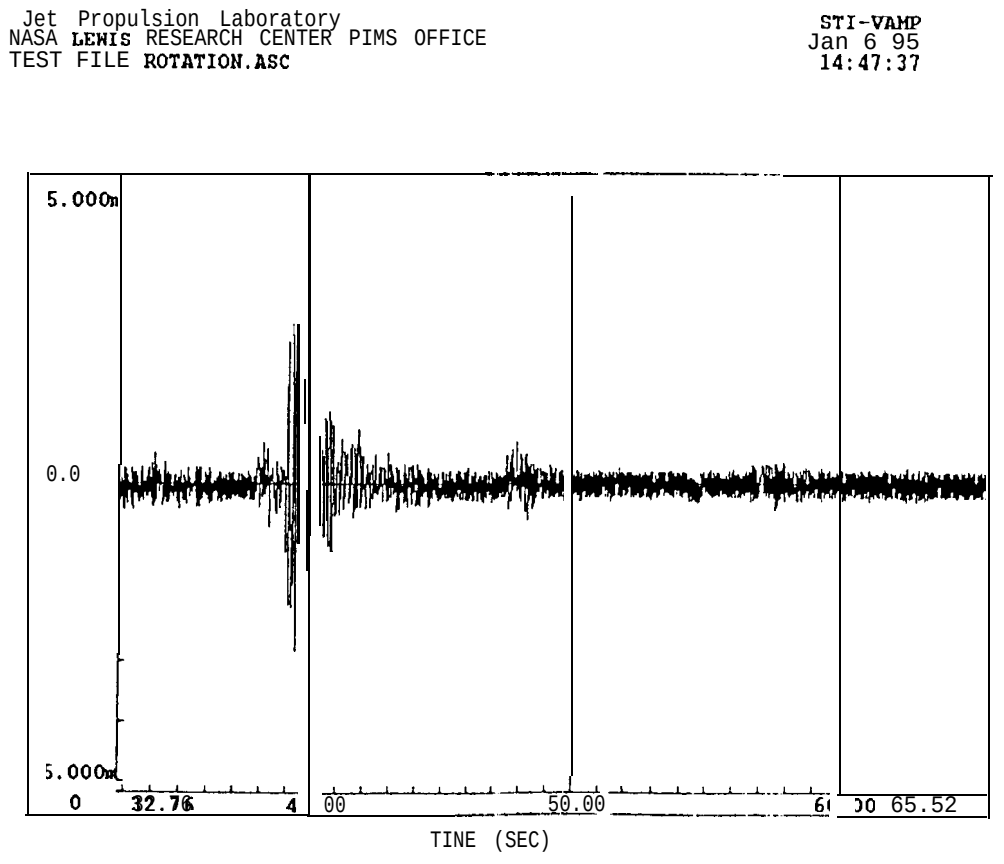
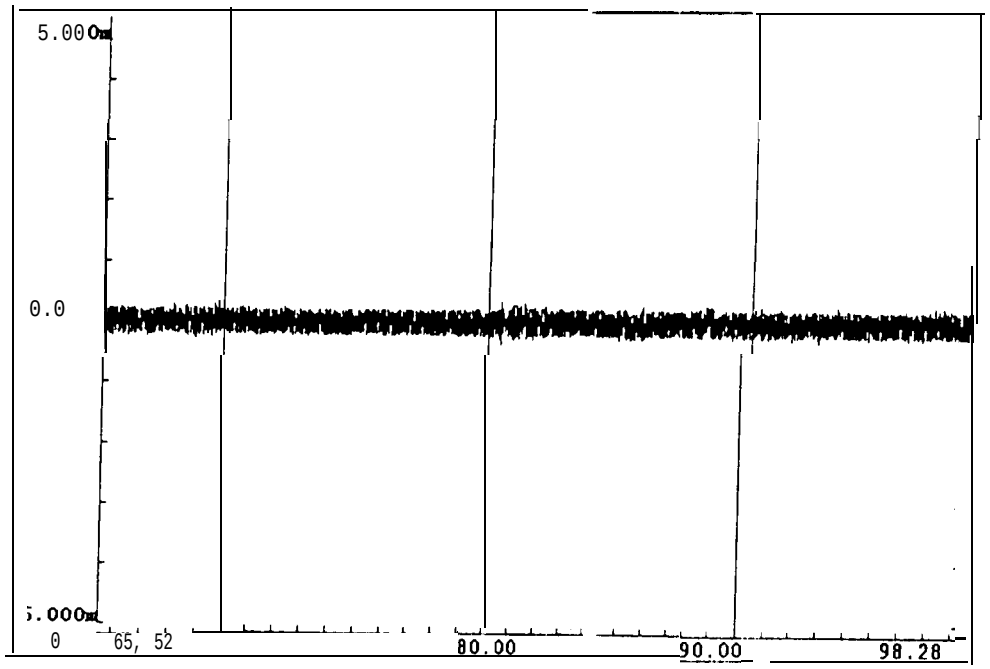


Figure 13. File: **ROTATION.ASC,** Time History



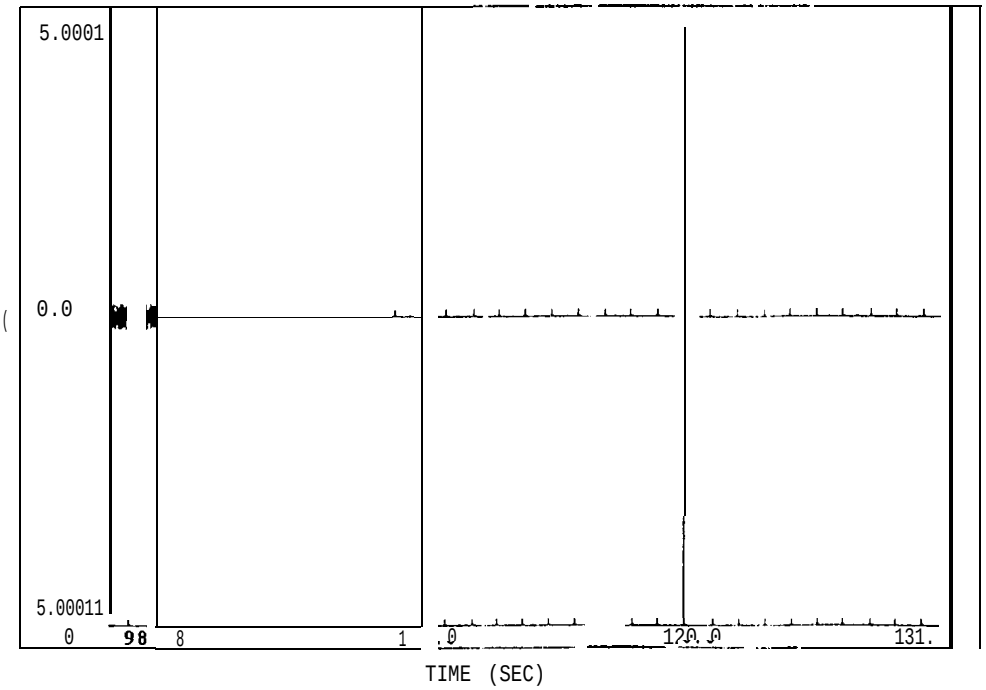


Figure 13. File: ROTATION.ASC, Time History (CONT.)

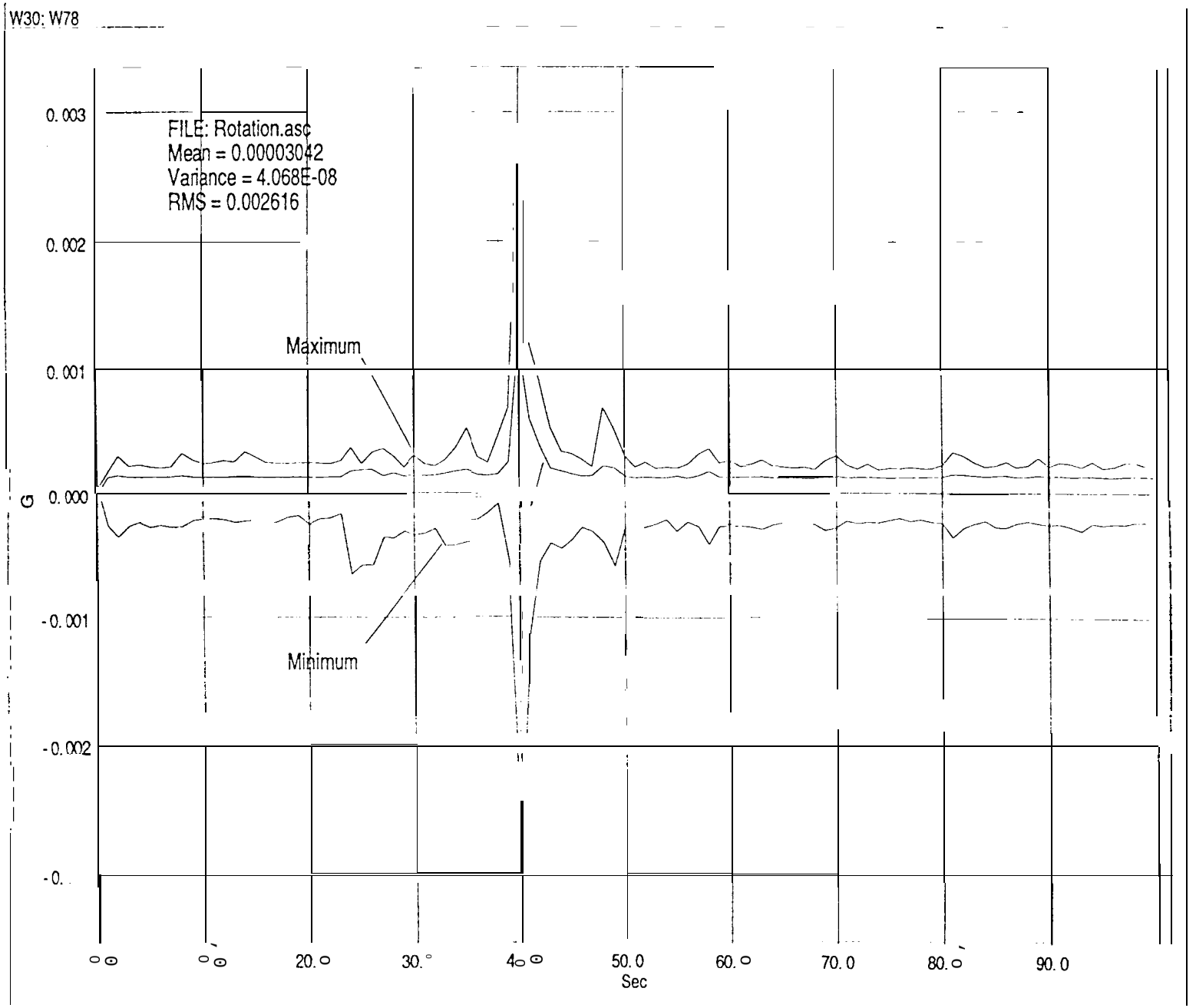


Figure 14. File: ROTATION.ASC, Running Time Parameters

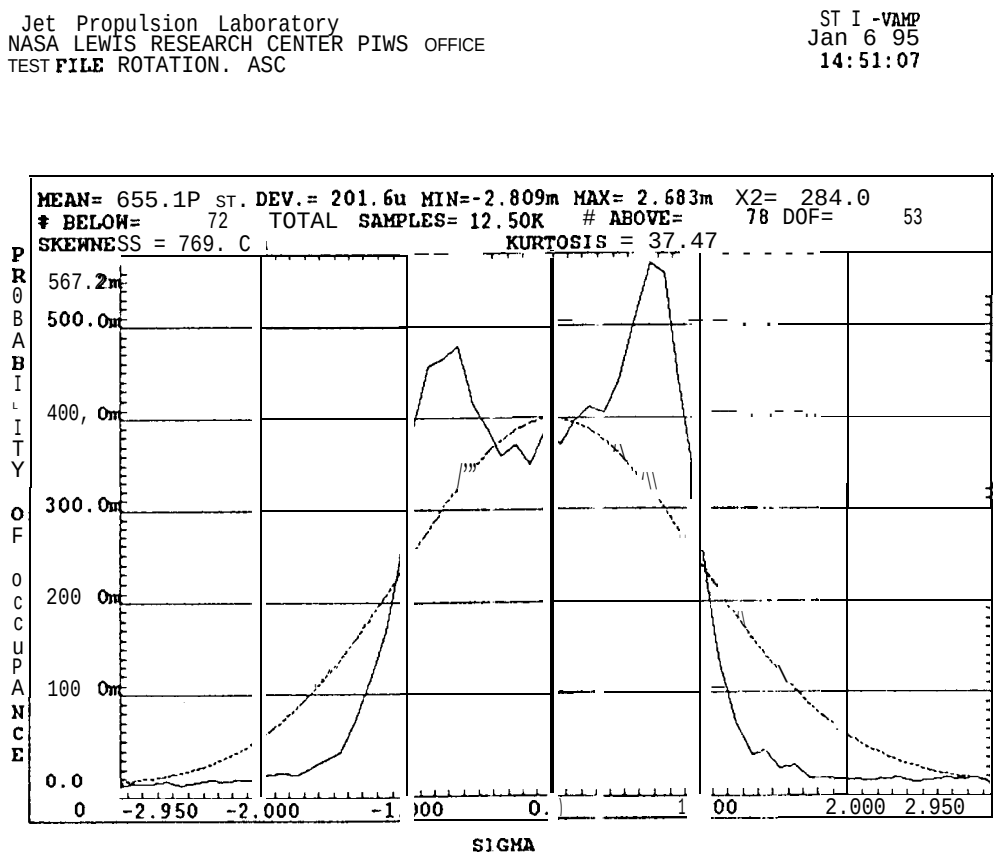


Figure 15. File: **ROTATION.ASC, Probability** Density

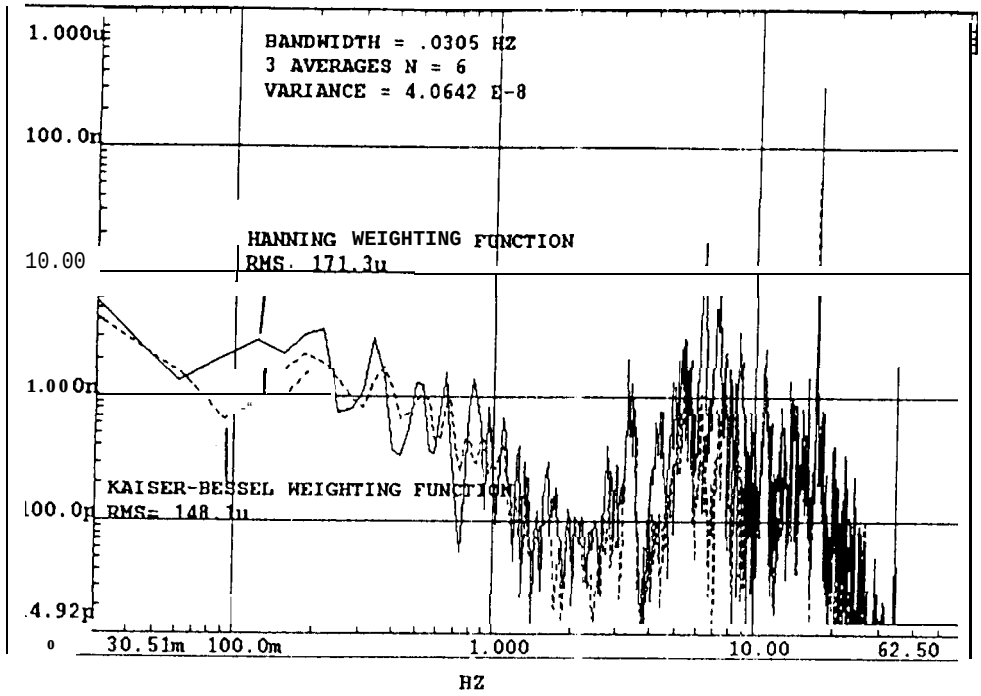


Figure 16A. File: **ROTATION.ASC,** I'SD, 3 Averages

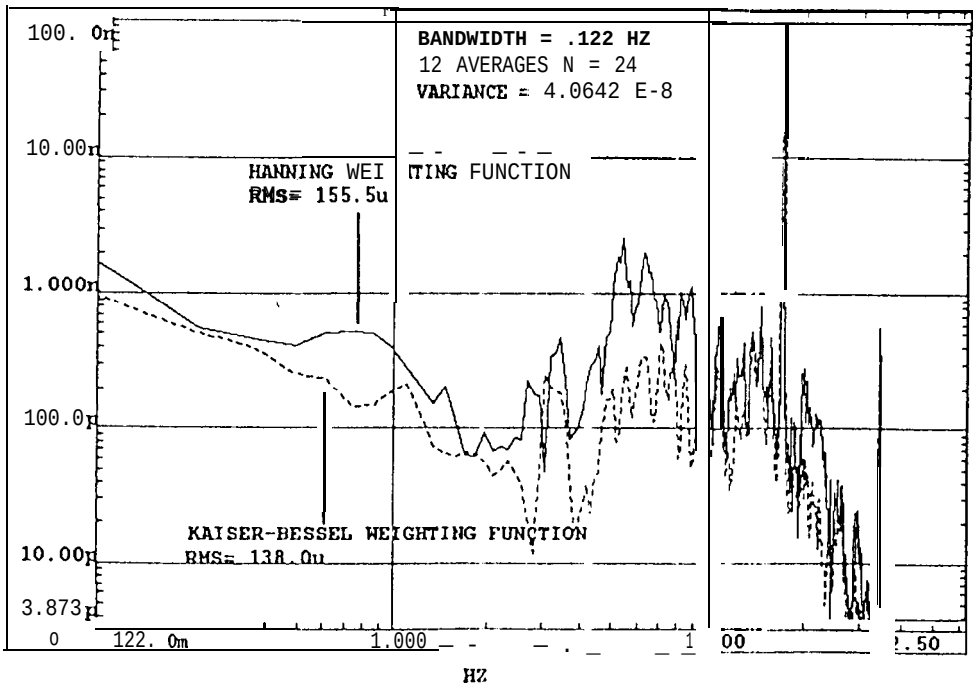


Figure **16B. File: ROTATION.ASC,** PSD, 12 Averages

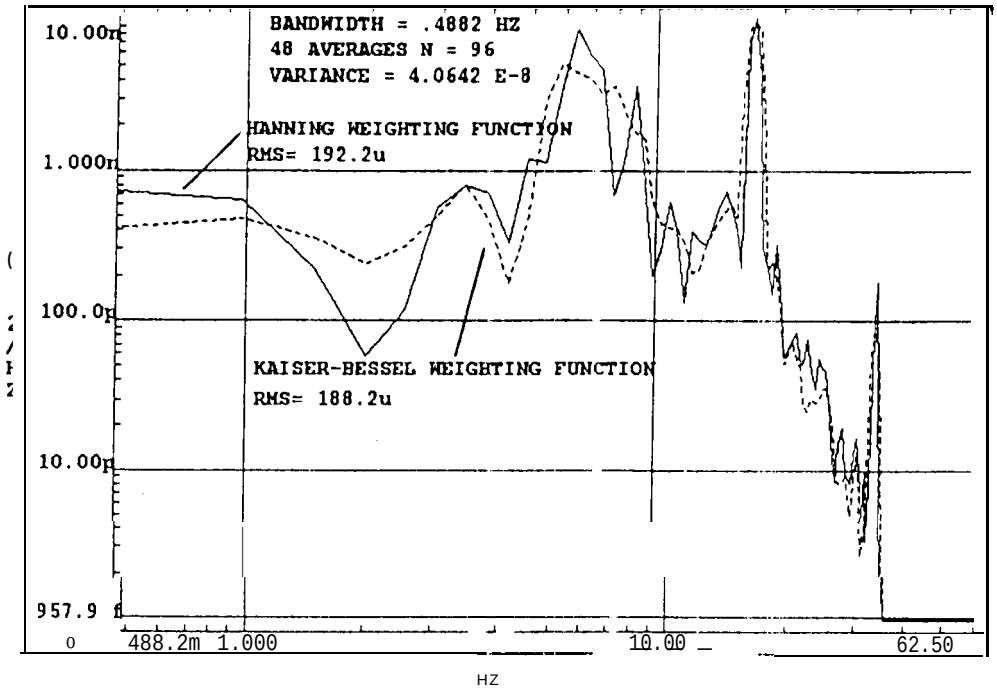
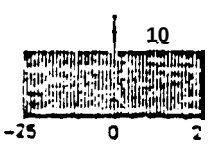
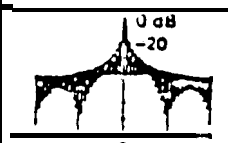
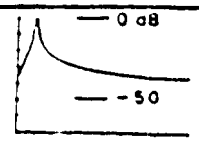
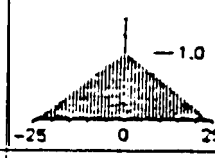
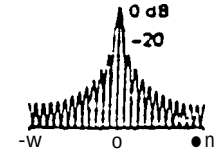
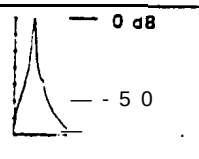
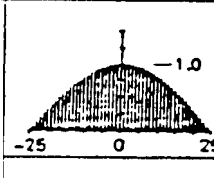
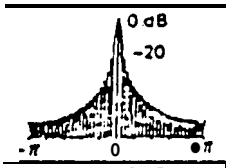
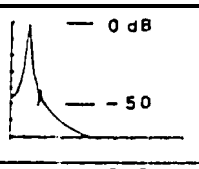
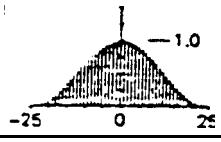
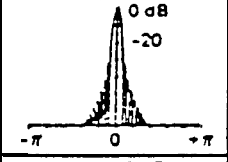
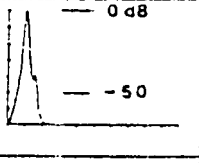
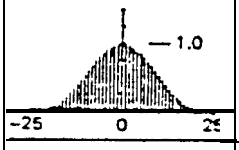
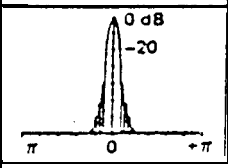
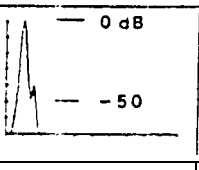
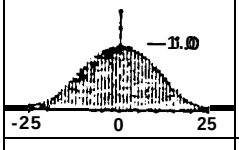
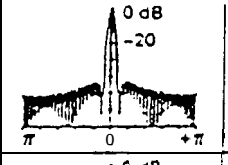
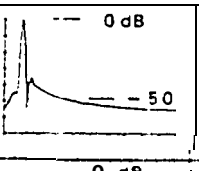
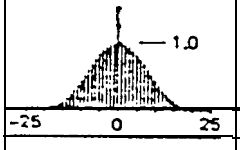
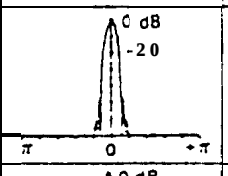
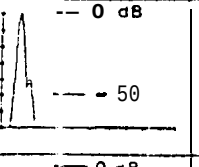
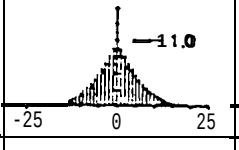
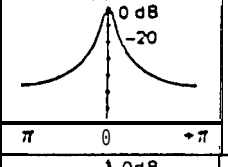
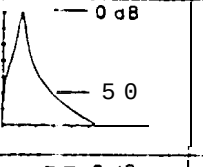
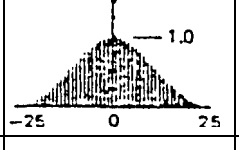
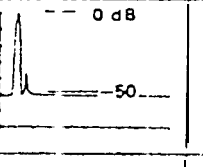
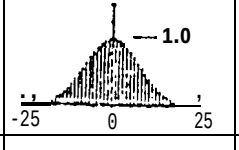
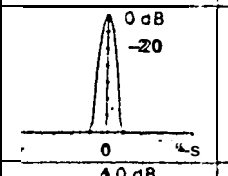
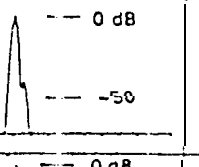
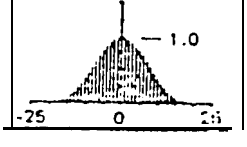
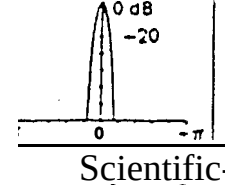
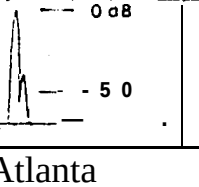


Figure 16C. File: **ROTATION.ASC,** PSD, **48** Averages

COMPARISON OF WEIGHTING FUNCTIONS

	TIME	FREQUENCY	TWO-TONE SPECTRAL RESOLUTION	HIGHEST SIDELOBE LEVEL	ASYMPTOTIC ROLL-OFF (dB/OCTAVE)	BA NO	NOTI (1) 3 dB
1 RECTANGLE				-13		1	0.88
2 FEJER or TRIANGLE				-26	12	1.3	1.28
3 COSINE				-23	12	1.2	1.2
4 HANNING Of (COSINE)²				-32	18	1.5	1.4
5 (COSINE)'				-39	24	1.7:	1.56
6 HAMMING or (COSINE)² + PEDESTAL				-42	6 dB/OCT. BEYOND 5 Δf	1.36	1.30
7 [COSINE)'				-48	30	1.94	.86
8 TRIPLET or (COSINE)² X EXPONENTIAL				NONE	18 10 NOTONII	2.02	.87
9 DOLPH-TCHEBYCHEV				-50	0	1.51	.44
10 GAUSSIAN				-64	26	1.90	1.79
11 KAISER-BESSEL				-70	38.5	1.80	.71

SP-011 (11/81)

Scientific-Atlanta
Spectral Dynamics Division
United States: P.O. Box 23575 • San Diego, CA 92123-0575 • (619) 268-7100 • TWX 910-335-2022
Europe: Horton Manor • Stanwell Road • Horton, Slough, SL3 9PA, England • Telephone: Colnbrook 3211 . Telex: 849833